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Technical feasibility of the use of topsoil in the composition of substrates of Caatinga forest species

Viabilidade técnica do uso do topsoil na composição de substratos de espécies florestais da Caatinga

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Adriano Alves de Andrade
Master in Environmental Sciences
Institution: Instituto Federal de Alagoas (IFAL) – Campus Marechal Deodoro
Address: Rua Lourival Alfredo, 176, Marechal Deodoro - AL, Brasil, CEP: 57160-000
E-mail: aaa8@aluno.ifal.edu.br

Marcelo Cavalcante
Doctor in Animal Science, Forage and Pasture
Institution: Instituto Federal de Alagoas (IFAL) – Campus Marechal Deodoro
Address: Rua Lourival Alfredo, 176, Marechal Deodoro - AL, Brasil, CEP: 57160-000
E-mail: marcelo.cavalcante@ifal.edu.br

Rodrigo Gomes Pereira
Doctor in Agronomy
Institution: Universidade Federal do Agreste de Pernambuco (UFAPE) – Campus Garanhuns
Address: Av. Bom Pastor, s/n, Boa Vista, Garanhuns - PE, Brasil, CEP: 55292-270
E-mail: rodrigo.pereira@ufape.edu.br

Cícero Gomes dos Santos
Doctor in Soil Science
Institution: Universidade Federal de Alagoas (UFAL) – Campus Arapiraca
Address: Av. Manoel Severino Barbosa, s/n, Bom Sucesso, Arapiraca – AL, Brasil, CEP: 57309-005
E-mail: cgomes@arapiraca.ufal.br

ABSTRACT

Mining generates great environmental impacts, in addition to a large amount of waste. In order to comply with environmental legislation, the production of seedlings is one of the actions carried out, which requires a large volume of substrates, generally commercial. The topsoil it is a residue with physical-chemical characteristics with potential for agricultural use, present in large quantities, reaching 33 thousand m3. This research aimed to know the technical feasibility of topsoil added to commercial substrate for the production of seedlings of four native Caatinga species. The experiment was carried out in a completely randomized design, in a 5 x 4 factorial model, with five topsoil levels (0, 25, 50, 75 and 100%) and four species [‘Canafístula’ (Peltophorum dubium), ‘Farinha Seca’ (Albizia hasslerii), ‘Timbaúba’ (Enterolobium contortisiliquum) and ‘Ipê Branco’ (Tabebuia roseo-alba)]. Considering the Dickson quality index, for the species ‘Canafístula’ and ‘Ipê Branco’, 74.1 and 36.1% are the maximum limits of topsoil and, for ‘Farinha Seca’ and ‘Timbaúba’, up to 100% can be used. In general, the addition of topsoil to the substrate will allow savings of 77% in substrate costs, making its use in the production of forest seedlings economically viable and environmentally correct.

Keywords: Abarema Langsdorfii, Enterolobium Contorstisiliquum, Peltophorum Dubium, Tabebuia Roseo-Alba, semiarid region.

RESUMO
A mineração gera grandes impactos ambientais, além de grande quantidade de resíduos. Para atender a legislação ambiental, a produção de mudas é uma das ações realizadas, que necessita de grande volume de substratos, geralmente comerciais. A camada superficial do solo é um resíduo com características físico-químicas com potencial para uso agrícola, presente em grandes quantidades, chegando a 33 mil m3. Esta pesquisa teve como objetivo conhecer a viabilidade técnica da adição de solo superficial a substrato comercial para produção de mudas de quatro espécies nativas da Caatinga. O experimento foi conduzido em delineamento inteiramente casualizado, em modelo fatorial 5 x 4, com cinco níveis de solo superficial (0, 25, 50, 75 e 100%) e quatro espécies [Canafístula (Peltophorum dubium), Farinha Seca (Albizia incômodorii), Timbaúba (Enterolobium contortisiliquum) e Ipê Branco (Tabebuia roseo-alba)]. Considerando o índice de qualidade de Dickson, para as espécies Canafístula e Ipê Branco, 74,1 e 36,1% são os limites máximos da camada superficial do solo e, para Farinha Seca e Timbaúba, pode-se utilizar até 100%. Em geral, a adição de topsoil ao substrato permitirá economia de 77% nos custos com substrato, tornando-se economicamente viável e ambientalmente correto seu uso na produção de mudas florestais.

Palavras-chave: Abarema Langsdorfii, Enterolobium Contorstisiliquum, Peltophorum Dubium, Tabebuia Roseo-Alba, região semiárida.

1 INTRODUCTION

The Caatinga is the largest dry tropical forest, located in the Northeast region of Brazil, which occupies 11% of the national territory, equivalent to 844.5 thousand km^2, present in 10 States (Freire et al., 2021). It is a biome divided into ecoregions that harbor several endemic plant and animal species and genera (Teixeira et al., 2021). In an advanced state of degradation, it is estimated that less than 57.4% of the vegetation is preserved (INPE, 2022), due to housing, mining, livestock and agriculture activities (Pessoa and Marco Júnior, 2023), in addition to the illegal and unsustainable extractive exploitation of firewood and animals for domestic purposes (MMA, 2023), showing the impact of social vulnerability on the biome.

Between 1985 and 2020, there was a reduction of 150 thousand km^2 of primary vegetation, in which 74.7% were replaced by agricultural activity, with the presence of some areas in an advanced state of desertification (Marques, 2022). Currently, the Caatinga has been identified as the most critical Brazilian biome with regard to the conservation of its biodiversity, being one of the most threatened and altered by anthropic action, which puts countless species at risk of extinction (Freire et al., 2021).

The occurrence of reserves of metallic substances (Cu, Cr, Fe, Ni, Au and V) in several regions of the Caatinga (ANM, 2022), makes mining an important source of revenue for the country. However, it brings challenges from an ecological point of view, as it promotes the removal of vegetation, producing large volumes of waste, which result in loss of fauna and flora diversity. It also causes damage to human health, as it pollutes the air through suspended particles or gases emitted from burning fossil fuels, in addition to polluting water and soil (Souza and Valadares, 2022). From a social point of view, Pacheco and Santos (2019) highlighted problems related to violence, housing, education and health, transportation, as they are not contemplated in the actions developed by the mining company.

Before mineral extraction, there is the suppression of native vegetation and then the removal of the surface layer of the soil, horizons O and A (topsoil), considered mining residue that is deposited in specific locations, to be used in future actions of post-mining environmental recovery, a period that could take more than 10 years, undergoing processes of leaching and oxidation of organic matter. Brazilian legislation provides for forest environmental compensation, requiring the undertaking to present a Plan for the Recovery of Degraded Areas (Decree No. 97,632/1989), as well as the implementation of Conservation Units (Law No. 20,922/2013).

The production of forest seedlings of native species is one of the actions aimed at minimizing the impacts of mining on the environment. The number of seedlings produced follows the ratio of 3:1, that is, for each tree suppressed, three new ones must be planted, reaching at least 20,000 seedlings/year. The commercial substrates used, in addition to the large volume and associated costs, may not be adapted to native species. However, topsoil could become a sustainable alternative, with reduced costs, from the use of mining waste. The few studies indicated that topsoil facilitated the association of *Periandra mediterraneaon* (Fabaceae) with nitrogen-fixing bacteria, improving its development (Figueiredo et al., 2018).

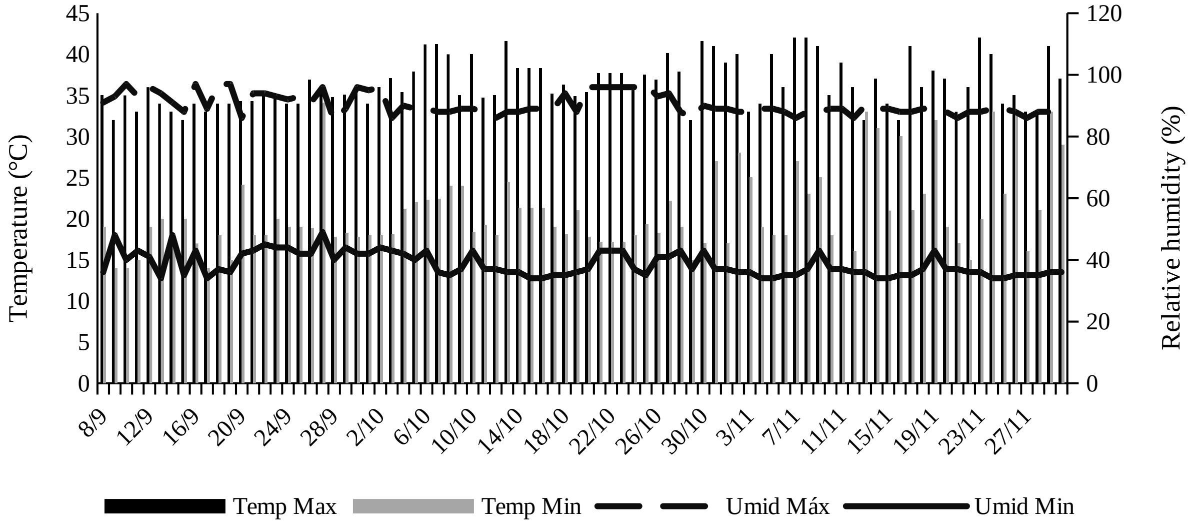
This research aimed to evaluate the technical feasibility of using topsoil in the composition of substrates for the production of seedlings of Caatinga species.

2 MATERIALS AND METHODS

2.1 LOCAL

The experiment was carried out between September and November 2022 in the seedling nursery of 'Mineração Vale Verde do Brasil Ltd.', of the chapel type, surrounded by shade (50% of light incidence), under the geographic coordinates 9° 40' 45,59" S e 36° 47' 05.7" W, municipality of Craíbas/AL. The climate in the region is BSh, hot semi-arid, according to the Köppen classification, with annual average temperatures, minimum and maximum, relative humidity and pluvial precipitation of 19.9 and 29.9ºC, 70.5% and 49,0 mm, respectively (Climate-Data, 2023). Using a digital thermo-hygrometer, model LCD-DC103, variations in temperature and relative humidity were monitored during the experimental period (Figure 1).

Figure 1. Variation of temperature (ºC) and relative humidity (%) inside the seedling nursery during the experimental period.



Source*:* Authors' elaboration.

2.2 EXPERIMENTAL DESIGN AND TREATMENTS

The experiment was implemented in a completely randomized design, factorial arrangement 5 x 4, composed of five topsoil levels (0, 25, 50, 75 and 100% topsoil replacing the commercial substrate) and four Caatinga species [‘Canafístula’ (*Peltophorum dubium* Spreng. Taub.), ‘Farinha Seca’ (*Albizia hasslerii* Chod. Burkart), ‘Timbaúba’ (*Enterolobium contortisiliquum* Vell. Morong) and ‘Ipê Branco’ (*Tabebuia roseo-alba* Ridl. Sandwith)], with four replications, totaling 100 plots, in which each plot was composed by nine seedlings.

The seeds of the species were collected from mother trees located at the Advanced Post of the Caatinga Biosphere Reserve, belonging to ‘Mineração Vale Verde Ltd.’, in Caríbas, Alagoas - Brazil. The topsoil, with no history of agricultural use, was obtained after carrying out the vegetation suppression services, in the 0 to 30 cm layer of the soil, in which the material was transported to a specific deposit, in the open, with a capacity of 33,000 m^3, according to the programs linked to the environmental licensing of the copper exploration project. The commercial substrate was Tropstrato Florestal® (‘Genfértil Composto Orgânico Ltd.’, Campinas, São Paulo - Brazil), consisting of pine bark, vermiculite, charcoal, simple superphosphate and products formulated by third parties, with a minimum water retention capacity of 130%, and density (dry basis) of 190 kg m^{-3}. Topsoil and commercial substrate samples were sent for chemical analysis, where the results are shown in Table 1.

Table 1. Chemical analysis of topsoil and commercial substrate.

Characters	topsoil	Commercial Substrate
pH (water)	5.8	5.4
P (mg dm^{-3})[1]	5.0	18.0
Na (mg dm^{-3})[1]	67.0	2000.0
K (mg dm^{-3})[1]	139.0	7000.0
Ca ($cmol_c$ dm^{-3})[2]	2.9	6.3
Mg ($cmol_c$ dm^{-3})[2]	1.3	4.7
Al ($cmol_c$ dm^{-3})[2]	0.0	0.13
H ($cmol_c$ dm^{-3})[3]	2.3	1.87
S (Sum of bases)	4.85	37.6
Organic matter (%)	1.95	57.5
Iron (mg dm^{-3})[1]	332.1	198.2
Copper (mg dm^{-3})[1]	1.35	2.25
Zinc (mg dm^{-3})[1]	0.01	0.15
Manganese (mg dm^{-3})[1]	0.55	0.65

Note: Analytical methods = [1]Mehlich; [2]KCl to 1N; [3]Calcium acetate pH 7.0. Source: Authors' elaboration.

The physical analyses of the topsoil of very coarse sand, coarse sand, medium sand, fine sand, very fine sand, silt and clay were 30, 115, 287, 280, 88, 109 and 91 g kg^{-1}, respectively, classifying it like sand loam soil.

2.3 EXPERIMENTAL MANAGEMENT

The seedlings were produced in non-toxic plastic tubes, black polypropylene, with a capacity of 290 mL, arranged in plastic trays with 54 cells, in which there was manual sowing of three seeds $tube^{-1}$, at a depth of 1.5 cm. At 30 days after sowing, thinning was performed, leaving the seedling more vigorous. Irrigations were daily, performed with the aid of a microsprinkler system with a flow of 0.96 m^3 h^{-1}, using a system with manual activation, for 40 minutes, twice a day, at 10:00 am and 3:00 pm.

2.4 VARIABLES ANALYSED

At 90 days after sowing, in five seedlings of the useful area of the plot, the number of leaves (NL; units); collar diameter (CD; mm), measured at the seedling neck with the aid of a caliper; seedling height (SH; cm), measured from the collar to the apex of the seedling with the aid of a measuring tape.

It was also quantified, with the aid of a digital analytical balance, the shoot mass (SM; g), after cutting in the region of the collar of the seedling with the aid of pruning shears; root mass (RM; g), obtained after separating the root from the substrate in running water; and total mass (TM; g), corresponding to the sum of SM and RM (g). With the data in hand, the Dickson Quality Index (DQI) proposed by Dickson et al. (1960), where:

$$DQI = \frac{TM\,(g)}{\frac{SH\,(cm)}{CD\,(mm)} + \frac{SM\,(g)}{RM\,(g)}}$$

2.5 STATISTICAL ANALYSIS OF DATA

Initially, the assumptions of analysis of variance (Anova) were tested, applying the Tukey, Durbin Watson, Bartlett and Shapiro-Wilk tests for non-additivity, independence of residuals, homoscedasticity and normality of errors, respectively, for each variable. Next, Anova was performed, using the Scott-Knott test for species and polynomial regression for topsoil levels, using the ExpDes package, version 1.2.2 (Ferreira et al., 2014). All analyses were performed using the R software (R Core Team, 2022).

3 RESULTS AND DISCUSSION

3.1 SUMMARY OF ANOVA

Significant differences ($p < 0.05$) were observed between Caatinga species and no effect ($p > 0.05$) of topsoil levels on number of leaves (Table 2). However, for the other variables, there was a significant Species x Topsoil interaction, indicating that seedling behavior was influenced by substrate composition.

Table 2. Calculated F values for the analyzed variables.

Variables	Variation Sources			CV (%)
	Species (S)	Topsoil (T)	S x T Interaction	
Number of leaves	14.4**	0.31 ns	1.22 ns	20.1
Collar diameter	87.7**	7.5**	4.1**	12.2
Plant height	3178.7**	10.2**	16.2**	5.6
Shoot mass	660.8**	6.7**	16.4**	14.3
Root mass	436.8**	21.7**	9.2**	16.9
Total mass	666.3**	12.2**	4.8**	14.0
Dickson Quality Index	38.5**	11.4**	3.1**	25.9

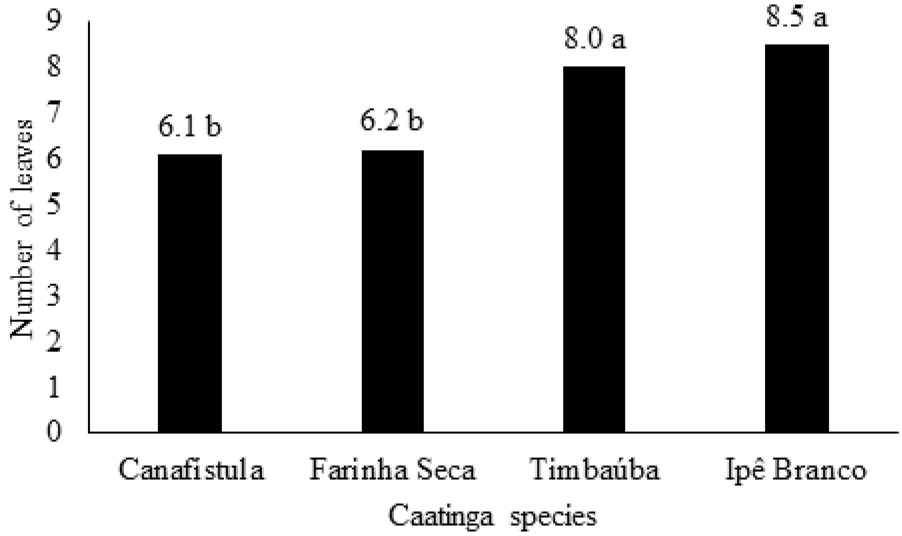
Note: CV: coefficient of variation. **, ns: significant at $p < 0.01$ and not significant at $p > 0.05$ by F-test, respectively. Source: Authors' elaboration.

The coefficient of variation ranged from 5.6% for plant height, indicating excellent experimental precision, to 25.9% for DQI, which tends to show greater variation because it is an index formed by the combination of other variables. Also, when considering the green mass of the plants, there is greater variability within the experimental unit due to the variation in the water content in each plant, directly influencing this statistical parameter (Lúcio et al., 2011). Still, the genetic variability observed in native populations, due to natural pollinations, also influence the phenotypic variability observed in the progenies (Feres et al., 2012), reflecting on the coefficient of variation.

3.2 NUMBER OF LEAVES

‘Timbaúba’ and ‘Ipê Branco’ species did not differ from each other ($p > 0.05$) and had the highest number of leaves ($p < 0.05$) when compared to ‘Canafístula’ and ‘Farinha Seca’ species (Figure 2). This is an important characteristic, as it is in the leaf that the conversion of light energy into chemical energy occurs, directly linked to the quality of the seedling. According to Oliveira et al. (2019), the four species studied had a minimum of three pairs of leaves, a criterion adopted by forestry companies to classify seedling quality.

Figure 2. Number of leaves of seedlings of four Caatinga species. Means, followed by the same letter in the columns, belong to the same group by the Scott-Knott test ($p > 0.05$).



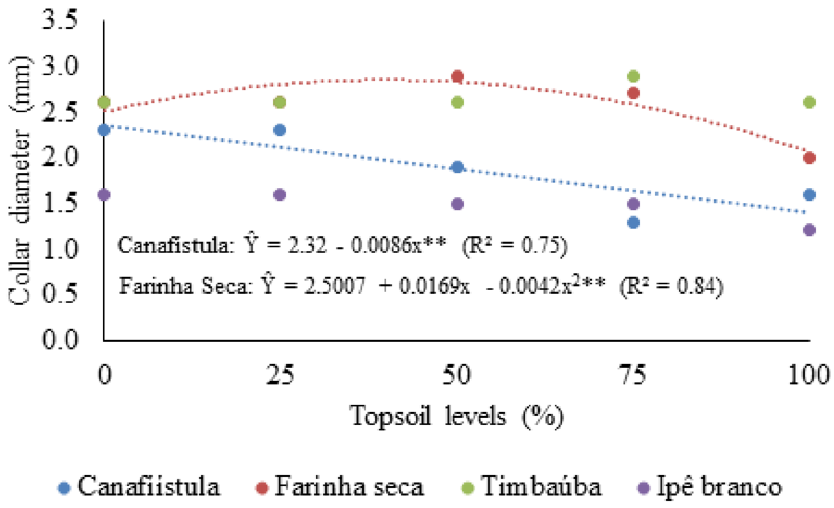
Source: Authors' elaboration.

Researches with similar results were observed by Zuffo et al. (2021), for ‘Canafístula’, with an average of 8.8 leaves; ‘Timbaúba’, with 8.7 leaves (Araújo and Paiva Sobrinho, 2011); and ‘Ipê Branco’, with nine leaves (Gonçalves et al., 2013); and superior results were obtained by Barbeiro et al. (2018), in which ‘Farinha Seca’ had 12.3 leaves. This information, despite the differences in treatments, management practices and the region where they were developed, indicate that topsoil may become an option for seedling production, in view of the importance of the number of leaves.

3.3 COLLAR DIAMETER

The collar diameter is an important variable, as it is related to the survival rate of the seedling after transplantation, due to the ability to generate and develop roots, from the translocation of nutrients (Almeida et al., 2020). According to Gonçalves et al. (2019), 2.2 mm is the minimum diameter for seedlings suitable for transplanting. In this sense, only ‘Ipê Branco’ had an average lower than the minimum in all treatments (Figure 3). If we consider the results obtained by Silva et al. (2021), in which the diameter of the ‘Ipê Branco’ ranged from 1.98 to 2.71 mm at 80 DAP, it is possible to infer that the substrates are not suitable for this species.

Figure 3. Collect diameter (mm) as a function of topsoil levels replacing the commercial substrate.



Source: Authors' elaboration.

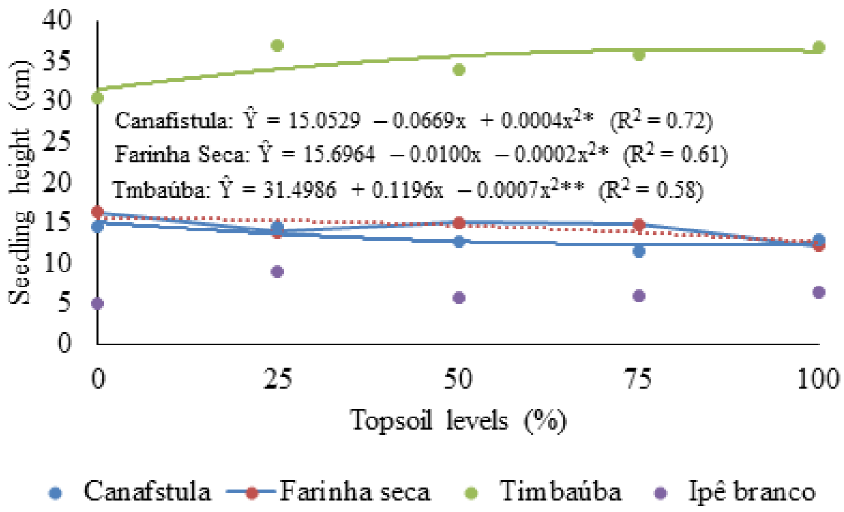
For the ‘Canafístula’ species, a linear reduction was observed with the addition of topsoil to the substrate, probably due to the low organic matter content (Table 1), which influences microporosity (water retention) and plant nutrition. In this sense, for the production of ‘Canafístula’ seedlings, 13.9% is the maximum limit of topsoil, if the seedling selection criterion for transplanting is the collar diameter.

For the ‘Farinha Seca’ species, the behavior was quadratic, in which the maximum diameter ($\hat{Y}_{max.}$ = 2.52 mm) could be obtained with 2.01% topsoil. However, considering the minimum diameter (2.2 mm), 10.3% topsoil will be the maximum inclusion level, with 81% reliability (R^2; Figure 3). For the ‘Timbaúba’ and ‘Ipê Branco’ species there was no effect of topsoil levels ($p > 0.05$).

3.4 SEEDLING HEIGHT

There was a significant difference ($p < 0.05$) between species at each level of topsoil inclusion, with ‘Timbaúba’ standing out, with the highest height (Figure 4). Considering that the average height of seedlings suitable for transplanting varies between 20 and 30 cm (Oliveira et al., 2016), only ‘Timbaúba’ exceeded this standard. According to Nascimento et al. (2021), it is the largest tree in the Caatinga, classified as a pioneer, fast-growing tree, explaining the observed results.

Figure 4. Seedling height (cm) as a function of topsoil levels replacing the commercial substrate.



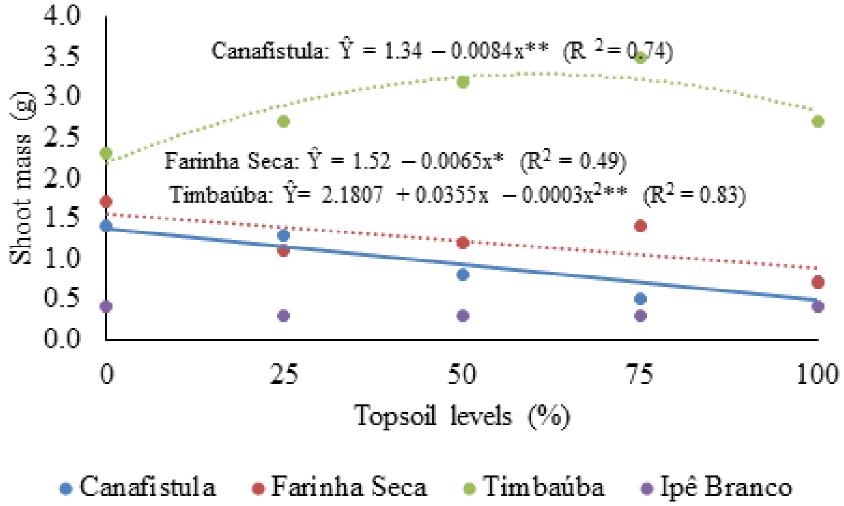
Source*:* Authors' elaboration.

Analysing the effect of topsoil levels on the species, it was observed that the data fit the quadratic model, for ‘Canafístula’ ($X_{max.}$ = 83.6%; $\hat{Y}_{max.}$ = 17.9 cm), ‘Farinha Seca’ ($X_{max.}$ = 25.0%; $\hat{Y}_{max.}$ = 15.8 cm) and ‘Timbaúba’ ($X_{max.}$ = 85.4%; $\hat{Y}_{max.}$ = 36.6 cm), however, without significant effect for ‘Ipê Branco’ ($p > 0.05$). In general, although the species ‘Canafístula’, ‘Farinha Seca’ and ‘Ipê Branco’ had averages below 20 cm, it is possible that the evaluation period (90 DAP) was insufficient, considering that Portela et al. (2001), at 150 DAP, Barbeiro et al. (2018) and Cardorin et al. (2021), at 180 DAP, observed mean heights of 20.4, 38.2 and 28.9 cm for the three species, respectively.

3.5 SHOOT MASS

The study of shoot mass showed a significant difference between the species, within each topsoil level, with ‘Timbaúba’ standing out at all evaluated levels (Figure 5), as it is the largest pioneer species in the Caatinga (Nascimento et al., 2021). ‘Ipê Branco’ had the lowest mass ($p < 0.05$) in all substrate compositions. In the research developed by Macedo et al. (2011), it was observed that treatments with higher nitrogen concentration (chicken litter) promoted greater shoot mass. Therefore, it is possible that the ‘Ipê Branco’ has a greater demand for this macronutrient in the early stages of growth.

Figure 5. Shoot mass (g) as a function of topsoil levels replacing the commercial substrate.



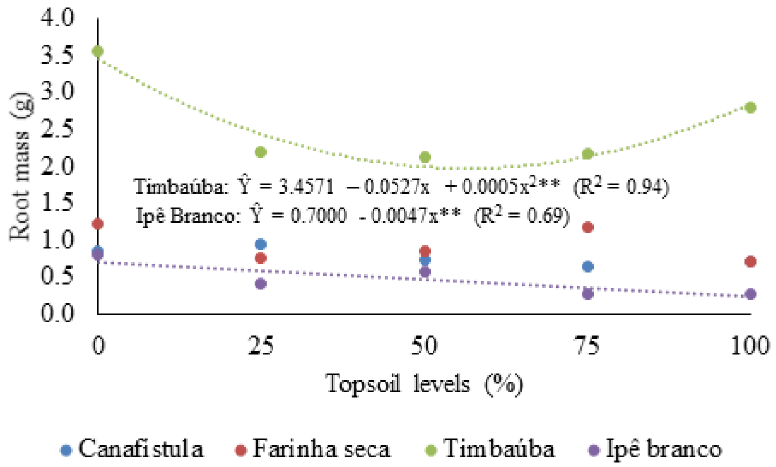
Source: Authors' elaboration.

For the ‘Canafístula’ and ‘Farinha Seca’ species, the data were adjusted to the linear model, with reduction of the aerial part mass from the increment of topsoil to the substrate; ‘Timbaúba’, fitted the quadratic model, in which the maximum mass of the aerial part ($X_{max.}$ = 3.23 g) was obtained with 59.2% topsoil inclusion in the substrate. For ‘Ipê Branco’, there was no effect of the substrates on the shoot mass ($p > 0.05$).

3.6 ROOT MASS

The evaluation of root mass showed a significant difference between species, with ‘Timbaúba’ standing out with the highest values (Figure 6).

Figure 6. Root mass (g) as a function of topsoil levels replacing the commercial substrate.



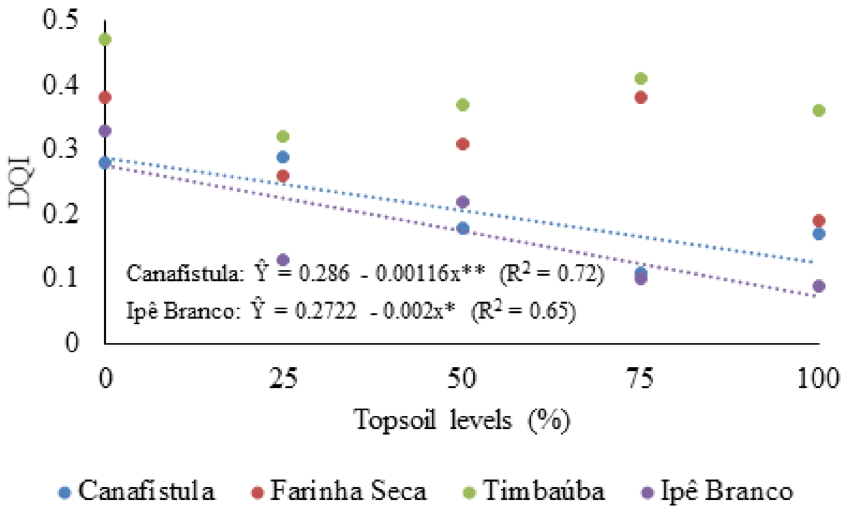
Source: Authors' elaboration.

Topsoil levels significantly reduced root mass for ‘Timbaúba’ and ‘Ipê Branco’ species, with quadratic and linear adjustment, respectively (Figure 6). Root production is linked to the availability of water, for cell elongation (Motte et al., 2019). With water scarcity, due to low water retention due to the predominance of topsoil in the substrate, there was a reduction in the roots of both species. However, for ‘Timbaúba’, from 52.7% of topsoil ($\hat{Y}_{min.}$ = 2.0 g), there was an increase in root mass. This is a physiological adjustment of this species, considering that water is a limiting factor, in which there is a reduction in leaf area (Figure 5), to minimize water loss through transpiration and increased root mass due to water deficit.

3.7 DICKSON QUALITY INDEX (DQI)

Unlike the criteria used to determine seedling quality (number of leaves, collar diameter and seedling height), DQI is a method that requires the destruction of evaluated seedlings. However, as it integrates different morphometric parameters, it is considered an important tool used to indicate seedling vigor (balance between aerial part and root system), allowing to predict the behavior of seedlings after transplanting, with an impact on their performance in the field (Gallegos-Cedillo et al., 2021). So, linear reduction of DQI was observed for ‘Canafístula’ and ‘Ipê Branco’ species with the addition of topsoil to the substrate. However, considering the minimum limit of 0.20 for the DQI (Dickson et al., 1960), the levels of 74.1 and 36.1% of topsoil are the maximum limits for these species, respectively. For ‘Farinha Seca’ and ‘Timbaúba’, there was no effect of topsoil on DQI (Figure 7).

Figure 7. Dickson Quality Index (DQI) as a function of topsoil levels replacing the commercial substrate.



Source: Authors' elaboration.

3.8 ECONOMIC EVALUATION

With the results obtained, it was possible to achieve economic perspectives regarding the production of seedlings, as well as productive savings provided by the adoption of the practices of using topsoil to replace commercial forest substrate (Table 3).

Table 3. Economic feasibility assessment of using topsoil to replace commercial substrate.

Espécies	Replacement of Topsoil (%)	Forest substrate (%)	Topsoil (g/tube)	Forest substrate (g/tube)	Only forest substrate (R$/1000 seedlings)	Substituição Topsoil (R$/1000 seedlings)
‘Canafistula’	74	26	122.5	44.2	166.67	44.17
‘Ipê Branco’	36	64	60.2	106.5	166.67	106.50
‘Farinha Seca’	100	0	166.7	-	166.67	--
‘Timbaúba’	100	0	166.7	-	166.67	--
Total					666.67	150.67

Source: Authors' elaboration.

From the results obtained in the Dickson quality index, from the replacement of topsoil by 74% for ‘Canafístula’ (74%), 36% for ‘Ipê Branco’ and 100% for ‘Farinha Seca’ and ‘Timbaúba’, an average reduction of 77% was observed, in costs (Table 3). The use of topsoil as an alternative substrate for the production of seedlings of Caatinga species proved to be viable, in which the level varies according to the method of evaluating the seedling quality (NL, SH, CD, DQI) and the evaluated species.

4 CONCLUSION

In seedling production, there are different methods to determine seedling quality. Considering the number of leaves, the substrate composition does not influence the species; for the collar diameter, 13.9 and 10.3% of topsoil are the maximum limits for ‘Canafístula’ and ‘Farinha Seca’ species; plant height, 85.4% topsoil is recommended for ‘Timbaúba’; the Dickson quality index, for the ‘Canafístula’ and ‘Ipê Branco’ species, 74.1 and 36.1% are the maximum limits of topsoil and, for ‘Farinha Seca’ and ‘Timbaúba’, up to 100% can be bused.

By replacing the commercial substrate with topsoil, there is a 77% reduction in costs, which is an alternative that can be adopted by mining projects.

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